Analyses of Fatigue-Crack-Growth Databases for Use in Damage-Tolerance Approach for Aircraft Propellers and Rotorcraft

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Abstract

A large portion of the fatigue-crack-growth-threshold data in the literature is inappropriate due to the load-reduction test procedures that were used to generate these data. The author in collaboration with Dr. Scott Forth, NASA Langley Research Center (LaRC), is developing test procedures to generate threshold data under steady-state constant-amplitude loading conditions without any substantial load-history effects. A large test program on the development of these fatigue-crack-growth databases, for use in damage-tolerant analyses for aircraft propellers and rotorcraft components, is being conducted at NASA LaRC under a Memorandum of Agreement with the Federal Aviation Administration. This test program is being conducted to generate more accurate representations of the fatigue-crack-growth behavior in the near threshold regime and approaching fracture under a wide-range of loading conditions.

Project Objectives

The objectives of the research project are to: (1) develop test procedures to generate fatigue-crack-growth thresholds under constant-amplitude loading conditions, (2) analyze the test data on selected propeller and rotorcraft materials to develop the effective stress-intensity factor range against crack-growth rate relationship for use in damage-tolerance and durability analyses, (3) develop equation to predict the thresholds as a function of stress ratio (R), and (4) develop stress analyses of the compact specimen that will allow the use of displacement gages to monitor crack growth using extremely low applied loads. The matching funds from Mississippi State University (MSU) were used to purchase two 6-kip servo-hydraulic fatigue test machines.

Research Activities

Installation of the two 6-kip fatigue test machines has been made in the MSU Fatigue and Fracture Laboratory. Some preliminary tests conducted on compact tension C(T) specimens made of 7075-T351 (B = 0.5 in.) were used to check out the new fatigue test machines. These initial tests were conducted under compression-compression pre-cracking to initiate a crack at the machined notch [1]. Standard fatigue crack growth tests are now being conducted using the backface strain gage method to monitor crack growth.

Compact specimens with a machined notch are being subjected to compression-compression pre-cracking loads to initiate and grow a benign crack from the 60-degree notch tip. Compressive loads are being applied to the specimens using either pin loading in the holes or loading applied to the upper and lower edges of the specimens along the hole centerline. (Stress-intensity factors for the compact specimens subjected to these types of compressive loads are being generated.) Once the benign crack has been introduced into the specimen, low-level constant-amplitude loads, near the anticipated thresholds, will be applied.

Fatigue-crack-growth-rate data generated at NASA LaRC using these procedures have been received on the 7075-T7351 [2] and 7050-T6 alloys. The effective stress-intensity factor against crack-growth rate relations will be generated.

Crack growth in compact tension specimens are usually monitored by using either the crack-mouth-opening displacement gage or the backface strain gage. At the extremely low applied loads required to generate thresholds, the displacement gage can actually load the specimen and have a significant influence on the stress-intensity factors depending upon the applied loads. (It is recommended that the backface strain gage be used to generate data in the near threshold regime.) However, a stress analysis will be conducted to generate a stress-intensity factor solution for a displacement gage applied to the standard compact specimen, so that the displacement gage may be used.

Anticipated Results

(1) The resulting fatigue-crack-growth (ΔK_{eff}-dc/dN) relationships can be used in NASGRO (strip-yield model) or used to generate the stress-intensity factor (ΔK) against rate curves for use in AFGROW or any other life-prediction code requiring linear-elastic fracture mechanics (LEFM) procedures.

(2) More reliable life predictions for high-cycle fatigue components using the improved thresholds.

(3) Simple method to fit fatigue-crack-growth-rate data in the near threshold regime.

(4) Improved ASTM E647 Standard on fatigue-crack-growth-threshold determination.

(5) Fatigue-crack-growth-rate data generated in the near threshold regime using displacement gages can be corrected for loads induced by the displacement gage.

Accomplishments

(1) Stress-intensity factors for compact specimens subjected to various compressive loads have been generated.

(2) Stress-intensity factor equations have been developed for compact tension specimens with a displacement gage (requires force-displacement relation from displacement gage).

(3) The effective stress-intensity factor against crack-growth rate data has been analyzed and relations have been generated on the two 7000-series alloys.

References

[1] Pippan, R., Plöchl, L., Klanner, F. and Stüwe, H. P., “The Use of Fatigue Specimens Precracked in Compression for Measuring Threshold Values and Crack Growth,” ASTM Journal of Testing and Evaluation, Vol. 22, No. 2, 1994, pp. 98-103.

[2] Forth, S. C., Newman, Jr., J.C., and Forman, R.G., “Evaluation of Fatigue Crack Thresholds Using Various Experimental Methods,” Fatigue and Fracture Mechanics: 33rd Volume, ASTM STP 1417, W.G. Reuter and R.S. Piascik, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2002.